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REVIEW ARTICLE

Melliferous potential of *Mentha aquatica*

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The abundance and diversity of flowers have declined and bees are chronically exposed to numerous pressures such as cocktails of agrochemicals, parasites and predators, climate change, and lack of floral resources. Chronic exposure to multiple interacting stressors is driving honey bee colony losses and declines of wild pollinators, that may lead to “pollination crisis” in which crop yields begin to fall. Effective monitoring of pollinator populations is urgently needed to inform management strategies into the future. Additionally, strategies to reinforce the health and well-being of bees are needed. Based on the literature data gathered, we propose to use *Mentha aquatica* as an additional melliferous plant to support bees’ nutritional needs and develop diverse and nutritionally balanced plant communities. Here, we review the literature data concerning the implantation of the genus *Mentha* to complete the foraging schedule of *Apis mellifera* with special emphasis on its use as valuable nutritional resource and source of nutritional diversity. Additionally, we discuss the aspects of attractiveness of genus *Mentha* to honey bees. Our list of facts thus far reported in the literature on the use of *M. aquatica* will help in implementation of this specimen in helping the bees that are in difficult situation.

Keywords: *Apis mellifera*; *Mentha aquatica*; honey; melliferous specimens; bees

Introduction

The wild and managed bees stocks have declined over the past 50 years in many European Countries. At the same time, the demand for insect pollination of crops has increased and the importance of pollinators in providing such services has become apparent, leading to concern that we may be nearing “pollination crisis” in which crop yields begin to fall (Goulson et al., 2015; Traveset et al., 2017). The causes of bee decline, which may differ from place to place, are more likely due to habitat loss (Brown & Paxton, 2009; Vanbergen & Initiative, 2013), exposition to parasites and pathogens (Bootton et al., 2018), contamination of their environment with agrochemicals (Simon-Delso et al., 2017; Schott et al., 2017), lack of floral resources (Di Pasquale et al., 2013; Ouvrard et al., 2018; Vaudo et al., 2015) or combination of these factors (Coors & De Meester, 2008; Dickel et al., 2018; Sih et al., 2004). Sometimes one factor dominates over the others, like for example in South France where honey bees are often threatened by other insects such as the Asian hornet, *Vespa velutina* (Arca et al., 2014; de Haro et al., 2010; Franklin et al., 2017; Monceau et al., 2013; Turchi & Derijard, 2018). The problems related with the presence of *Vespa velutina* (Lepeletier, 1836) are especially evident in beekeeping field at Saint-Laurent-le-Minier where *Apis mellifera* (*Apis mellifera* Linnaeus, 1758) was decimated by this insect. This example is significant, as in the whole Gard Department every single hive is equipped with an Asian hornet trap.

As the honey bees are busy defending the hive, they produce less honey and as a consequence are weakened and spend less time supplying of provisions. To help, protect and re-establish populations of bees, a range of native and garden plants can be used. Local native plants are the four times more attractive than exotic flowers. The best guide of choosing is based on succession of flowering while the whole growing season. Colors, clump of flowers, diversity of shapes, quality of pollen and nectars are important parameters. However, a sequence of plants flowering through spring, summer and fall can support a range of bee species. Many examples have been reported in Conservation Pollinator Handbook (Shepherd, Buchmann, & Vaughan, 2003). We here propose, based on the literature data search, introduction of *M. aquatica* (*Lamiaceae* Lindl.) as a melliferous plant to support nutritional needs and improve host-plant species resource quality as well as develop diverse and nutritionally balanced plant communities to support bees that are weakened due to expositions to different stress factors. Restoring appropriate suites of plant species to landscapes can support diverse bee species populations and their associated pollination ecosystem services.

Discussion

Implantation of the genus *Mentha* to complete the foraging schedule of *Apis mellifera*

Mentha aquatica, hydrophytes *Mentha citrata*, *Mentha aquatica* and *Mentha hirsuta* and the common names

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Table 1. Flowering periods comparative between various species.

Species\month	J	F	M	A	M	J	J	A	S	O	N	D
<i>Castanea sativa</i>						x	x					
<i>Lavandula latifolia</i>							x	x	x			
<i>Lavandula stoechas</i>				x	x	x						
<i>Mentha aquatica</i>							x	x	x			
<i>Rosmarinus officinalis</i>	x	x	x									
<i>Thymus vulgaris</i>			x	x	x	x						
<i>Tilia cordata</i>				x	x	x						

“horse mint”, “marsh mint” or “water mint” appears in the literature as a melliferous flower that can be collected and used for honey production (Pasca et al., 2016; Terrab et al., 2005). *Mentha aquatica* is an herbaceous plant and perennial aromatic herb growing in marshes and damp places such as in Europe, tropical Africa, West Asia, and America. It belongs to the family Lamiaceae and to the genus *Mentha*, which is a native from north temperate regions and occurs in all five continents (Gobert et al., 2002, Tela botanica, 2018). Additionally, *M. aquatica* is listed as a least concern species (species for which the risk of extinction is in metropolitan territories) by the IUCN Red List of Threatened Species. The development of *M. aquatica* to complete the foraging schedule of bees is also a chance to take part in the preservation of the species (INPN).

In studies about the assessment of melliferous value in Roussillon, Monique Balayer (1990) revealed that advisable compensations can be sought to ensure an adequate quantity of nectar during periods affected by a deficit in spontaneous vegetation, mainly in the middle of summer and at the end of winter. Additionally, according to the data published by Polunin and Huxley (1965) and also by Lagacherie and Cabannes (2003), we have established a flowering calendar for species also known from honey production and we have compared it with the flowering period of *Mentha aquatica* (Table 1). The flowering period of *Mentha aquatica* is from July to September (Tela botanica, 2018).

In our study site, the beekeeping field at Saint-Laurent-le-Minier, where melliferous flora is dominated by chestnuts, *Castanea sativa* (Fagaceae, Mill.) the flowering period of *Mentha aquatica* can be complementary with the *C. sativa*. Furthermore, the flowering period of the latter usually falls earlier, due to global warming (Polunin & Huxley, 1965). The flowering period of *Mentha aquatica* can also be complementary with other plants such as *Lavandula stoechas* (Lamiaceae, Lam.), *Rosmarinus officinalis* (Lamiaceae, L.), *Thymus vulgaris* (Lamiaceae, L.) and *Tilia cordata* (Malvaceae, Mill.) but might compete with *Lavandula latifolia* (Lamiaceae, Medik.).

Genus *Mentha* as valuable nutritionally resource for *Apis mellifera*

The main resource of proteins and amino acids essential for the colony development and health is pollen. The

Table 2. The main honey plant contributors to melliferous potential in the research area of southwestern Vojvodina considering their indices of nectar and pollen production (Inp, lpp).

Plant species	Family	Indices	
		lpp	Inp
<i>Rubus caecius</i>	Rosaceae	4	4
<i>Cirsium arvense</i>	Asteraceae	2	4
<i>Cichorium intybu</i>		1	2
<i>Taraxacum officinale</i>		4	4
<i>Carduus acanthoides</i>		3	3
<i>Crepis setosa</i>		4	1
<i>Lythrum salicaria</i>	Lythraceae	4	2
<i>Trifolium pratense</i>	Fabaceae	4	4
<i>Medicago sativa</i>		0	4
<i>Lotus corniculatus</i>		0	4
<i>Trifolium repens</i>		4	4
<i>Amorpha fruticosa</i>		2	4
<i>Dipsacus laciniatus</i>	Caprifoliaceae	3	2
<i>Asclepius syriaca</i>	Apocynaceae	2	4
<i>Mentha aquatica</i>	Lamiaceae	1	4
<i>Stachys annua</i>		1	4
<i>Stachys palustris</i>		1	4
<i>Daucus carota</i>	Apiaceae	4	4
<i>Salix alba</i>	Salicaceae	4	4
<i>Salix caprea</i>		4	4
<i>Epibolium hirsute</i>	Onagraceae	3	3

pollen consumption is especially intense by young bees during brood breeding and the feeding of larvae and thus leads to stock depletion. Equally important nutrient is nectar. This mixture of water, sugars, mainly glucose α and β , fructose and sucrose, but also polysaccharides such as starch, proteins, lipids, minerals contains between 90 and 99% sugar in its dry matter (Afik et al., 2006; Elisens & Freeman, 1988; Galetto & Bernardello, 2003; Mallinger & Prasifka, 2017). Nectar harvest takes priority over other harvests pollen, water, and honeydew because nectar needs are continuous. Nectar and honeydew are used to produce honey, stored in hives, in order to feed their larvae to survive during winter. In the case of *Mentha aquatica* the nectar is secreted by the non-extrafloral nectar glands of the flower, i.e., the flower nectaries located on the vegetative parts of the plant (Nicolson et al., 2007). The intensity of nectar (Inp) and pollen production (lpp) of several spermatophytes was numerically expressed by D'Albore and Oddo (1981) and additionally by Umeljic (1999, 2003). Plants are classified into four categories for each of the designated indices: Inp/lpp 1 = poor nectar or pollen production; Inp/lpp 2 = good nectar or pollen production; Inp/lpp 3 = very good nectar or pollen production and Inp/lpp 4 = excellent nectar or pollen production. The main honey plant contributors to melliferous potential according to the work of Macukanovic-Jocic and Jaric (2016) in Vojvodina, are gathered in Table 2. According to these data, *Mentha aquatica* shows a poor pollen production (lpp = 1) but an excellent nectar production (Inp = 4). It seems judicious therefore, to study the distinguishing nectar features of *Mentha*

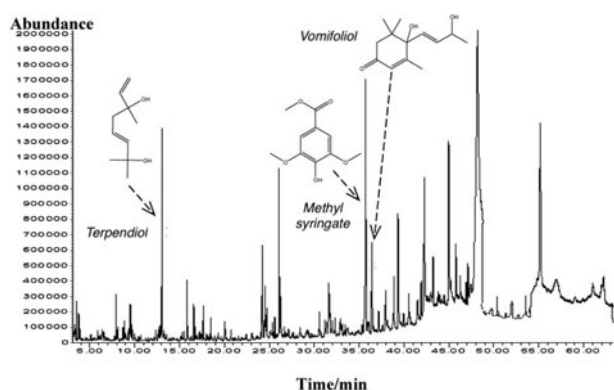


Figure 1. Representative chromatogram of the bee-stomach organic extractive (Jerković et al. 2010).

aquatica rather than the nutritional properties of its pollen which is relatively poor.

This high intensity of nectar production and the timing of the flowering period (Table 1) are correlated with Girard's definition of melliferous nectarine species according to which a species is called melliferous if its flowering is of long duration, that it produces nectar even in relatively dry weather, that it is not difficult on the nature of the soil and that its nectar is produced in quantity and quality Girard (1878). Moreover, the flowering period of *M. aquatica* (July to September) corresponds to the period when the temperature is often between 25 and 30 degrees, that is to say the temperature at which the activity of the foragers is the highest. On the other hand, the low pollen production is likely due to the botanical particularities of *M. aquatica*. Gynodioecy of this plant is worth mentioning, and only the plants with hermaphroditic flowers produce pollen, whereas plants with only sterile male flowers, in other words female plants, do not produce pollen (Guillot, 2010).

De Layens and Bonnier (1997) compiled a list of 33 plants divided and numbered into five categories (Table 3). The species assigned to number 5 correspond to the most melliferous species. The melliferous coenotic coefficient indicates the melliferous potential of each plant community, calculated with the total number of subjects, their percentage of abundance and frequency relative to other species, nectar and pollen production intensity indices, and environmental factors such as climate and altitude for example. Thus, the potential for *M. aquatica*, because it depends on its biocenosis, cannot be given as a fixed value in any geographical area (Macukanovic-Jocic and Jaric, 2016).

On the other hand, the nectariferous and polleniferous production indices for *M. aquatica*, makes that this plant is quite interesting for honey production, which represents a considerable asset because beekeepers are startled by the huge decrease in production, from 32,000 tonnes of honey produced in 1995 to 9000 tonnes in 2016 (Clement, 2017). Additionally, it is very important that honey comes from the natural foraging

of flowers and not from synthetic products such as scented syrups given by beekeepers.

A study on the chemical composition of organic extractives taken from bees stomach that have harvested nectar from species of the genus *Mentha*, revealed the presence of methyl methylsyringate (6.6%), terpendiol (5.0%), and vomifoliol (3.0%) (Figure 1) (Jerković et al., 2010). These compounds have been described as characteristic of the genus *Mentha*. The results show also the presence of fatty acids, fatty alcohols, aliphatic hydrocarbons and terpene derivatives. The unifloral botanical origin of all harvested honey samples was confirmed by palynology (up to 49% of *Mentha* spp. pollen dominated by *Mentha aquatica* L. and *Mentha pulegium* L.) according to recommended minimal values.

This analysis of organic extracts of the stomach content of the honey bees gives information about the composition of the nectar since it is well stored in bees stomach. As for the honey studied, the compounds would be methyl syringate, vomifoliol and hotrienol (from terpendiol I) (Jerković et al., 2010). Hotrienol is not specific to honey from *Mentha* spp. but its high percentage remains a notable feature. On the other hand, honeys in general contain a small quantity of vitamins, probably coming from the few grains of pollen they contain. Also honey from *M. aquatica* has the particularity to contain vitamin C. Indeed, the nectar of the plant itself is very rich in ascorbic acid.

Duffy and Stout (2008) studied the effects of plant density and nectar reward on bee visitation to the endangered orchid *Spiranthes romanzoffiana* (S. romanzoffiana Cham.) and showed that *Bombus pascorum* (Scopoli, 1763), *Bombus hortorum* (Linnaeus, 1761), and *Apis mellifera* regularly visit *M. aquatica*. Thus, for *Apis mellifera* this plant it is a source of pollen in addition to providing nectar.

What can pollen of *Mentha aquatica* add?

The wall of the spherical reticulated pollen of *Mentha aquatica* contains a layer called endexin, which is located between ectexin and intine (Weber & Ulrich, 2010) (Figure 2).

All species do not have this layer, but when it is present, it can be either compact, or spongy or in flakes, continuous or discontinuous. In the case of *Mentha aquatica*, the detection of endexin is difficult but it appears spongy or compact and shapes a continuous thin layer. Thus, endexin in the pollen of Angiosperms shows great diversity. It contains sporopollenin, lipids and proteins (Weber & Ulrich, 2010). Sporopollenine is not digestible but since endexin is permeable, it promotes its modification by the bee's enzymes and this would contribute to the nutritional diversity (Suarez-Cervera et al., 1994). Indeed, an undiversified diet causes an immunodeficiency in the honey bee. A varied pollen diet would allow a better resistance and a better longevity. Nutritional stress can

Table 3. List of the 33 melliferous species listed by De Layens.

Level of melliferous potential of selected species				
5 (highest)	4	3	2	1 (lowest)
<i>Pastinaca sativa</i> (Apiaceae)	<i>Angelica silvestris</i> (Apiaceae)	<i>Cirsium arvense</i> (Asteraceae)	<i>Mentha aquatica</i> (Lamiaceae)	<i>Eryngium campestre</i> (Apiaceae)
<i>Salvia pratensis</i> (Lamiaceae)	<i>Scrophularia aquatica</i> (Scrophulariaceae)	<i>Lappa tomentosa</i> (Asteraceae)	<i>Stachys palustris</i> (Lamiaceae)	<i>Polygonum hydropiper</i> (Polygonaceae)
<i>Origanum vulgare</i> (Lamiaceae)	<i>Mentha rotundifolia</i> (Lamiaceae)	<i>Heracleum sphondylium</i> (Apiaceae)	<i>Brunella vulgaris</i> (Lamiaceae)	<i>Polygonum aviculare</i> (Polygonaceae)
<i>Echium vulgare</i> (Boraginaceae)	<i>Onobrychis sativa</i> (Fabaceae)	<i>Lotus corniculatus</i> (Fabaceae)	<i>Daucus carota</i> (Apiaceae)	<i>Eupatorium cannabinum</i> (Asteraceae)
<i>Trifolium pratense</i> (Fabaceae)	<i>Verbena officinalis</i> (Verbenaceae)	<i>Gypsophila repens</i> (Caryophyllaceae)	<i>Centaurea paniculata</i> (Asteraceae)	/
<i>Melilotus arvensis</i> (Fabaceae)	/	<i>Centaurea jacea</i> (Asteraceae)	<i>Stachys recta</i> (Lamiaceae)	/
/	/	<i>Taraxacum dens-leonis</i> (Asteraceae)	<i>Teucrium chamaedrys</i> (Lamiaceae)	/
/	/	<i>Sinapis alba</i> (Brassicaceae)	<i>Leontodon autumnalis</i> (Asteraceae)	/
/	/	<i>Lappa minor</i> (Asteraceae)	<i>Girsium lanceolatum</i> (Asteraceae)	/

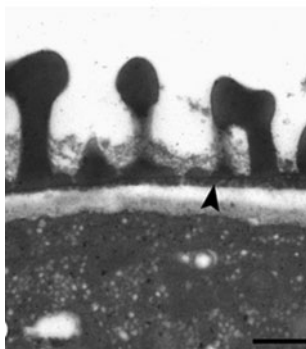


Figure 2. Cross-sections of pollen walls of *Mentha aquatica*: the arrowhead is showing the continuous thin endexine layer visible with transmission electron microscopy (TEM).

be an aggravating co-factor in the decrease of bee colonies. When a hive is next to a monofloral crop, the beekeeper will feed the bees with sugar syrup to prevent starvation. But, the beekeeping sector has no interest in using this method because it increases risks of adulteration of honey and, besides, sugar is much less nutritious than honey for *Apis mellifera*.

At the end of the chestnut bloom, pollen sources are scarce and nectar sources can disappear almost completely because of the drought which often occurs during summer (Louveaux, 1958). Pollen storage is regulated around the homeostatic set point to provide sufficient storage space for nectar to ensure winter survival (Weidenmüller & Tautz, 2002).

How can we know if honey bees will be attracted by *Mentha aquatica*?

There is a stimulus of flower selection depending on the abundance and composition of the nectar.

Furthermore, it is obviously necessary that the distance between the hive and the foraging area is not too far, but less than or equal to 1.5 km. Nectar is therefore the prime attraction factor of *Apis mellifera*. However, in fields and laboratories, experiments proposing to bees equal volumes of sugar solutions of different compositions but of the same concentration, show that the nature of the sugar present in the nectar does not have the same attractiveness. If a concentration of glucose and sucrose in a nectar is higher than the fructose concentration, bees will be more attracted. Therefore, the sugar composition of the nectar would be a factor influencing the foraging of bees. But there is no clear bond between the chemical constitution of a sugar and its attractive power on bees (Wykes, 1952). Chromatographic analyses of nectars show that the spectrum of sugars is very variable from one plant to another. It should be noted that *Mentha aquatica* belongs to Lamiaceae, for which the sucrose content dominates (Maurizio, 1959). In addition, linalool is present in free and bound forms in *Mentha aquatica*. The acyclic volatile terpene is very attractive for pollinator insects such as *Apis mellifera*. *M. aquatica* is a plant-pollinator (Raguso & Pichersky, 1999).

The role of *Mentha aquatica* in providing a supplementary forage source at times when other floral sources are historically scarce is really interesting. We can conclude that there is some value in having more of this plant available to bees. Another advantage of this food source is this wide geographical distribution around the World. Moreover, it is a perennial plant, but not intrusive. The only downside is that the plant prefers a wet environment, but doesn't tolerate other conditions. It is a facultative hydrophyte. Its crop is easy by germination on seeds or transplantation and

hydroponic crops with large growth rates and biomass. This species is a pollution tolerant or even a metal accumulator, but not a root-shoot translocator (Zuryak et al., 2002). As a consequence, the development of *M. aquatica* could have a dual use: a supplementary source of food for *A. mellifera* and an efficient metal accumulating plant to clean up soils or aquatic systems.

Conclusions

Mentha aquatica has strong positive effects in the nutrition of bees which are in a difficult context. The key features of the application of this plant are the long blooming period; complementary flowering calendar and an excellent nectar production. Additionally, *Mentha aquatica* can serve as a source of nutritional diversity and a source of components useful for the synthesis of queen pheromone and royal jelly, essential for the proper development of the bee colony. Already honey derived from *Mentha aquatica*, rich in vitamin C and with antioxidant properties, is produced in the USA. Our study focused on the melliferous potential for honey bees but *M. aquatica* is an undeniable source of nutritional diversity for both wild and managed bees.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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